Model Name and Version: MARKAL (MARKet ALlocation), Version 3.5 is in use by US Department of Energy (DOE)/Brookhaven National Laboratory (BNL) for the US national model.

Model Type: Partial equilibrium bottom-up energy system technology optimization model employing perfect foresight and solved using linear programming; with numerous model variants that expand the core model to allow for demand response to price (MACRO (non-linear) and Elastic_Demand (MED)), uncertainty (Stochastic), endogenous technology learning (ETL), material flows and multi-region (linked) models; plus new variants under development which support multi-criteria analysis (Goal Programming), and myopic execution (SAGE for EIA *IEO*).

Developer/Home Institution: Seventeen research institutions of OECD member countries participating in the International Energy Agency's Energy Technology Systems Analysis Programme (ETSAP)/Brookhaven National Laboratory/International Resources Group, Ltd.

Sector Detail: Energy sector total life cycle, including upstream activities such as mining, import/export, conversion and transformation, distribution, end users in industry, commercial and service sector, households, agriculture and transportation. A total of 70 end use categories are found in the US model.   Energy demand is exogenous under MARKAL and endogenous under MARKAL-MACRO/MED.

Regional Detail: Four regions for the residential heating/cooling in the US model. On the supply side, delivery costs are used to mimic distances of different resources to the demand center.

Technology Detail: Existing and new technology options in the US model include:
       119 resource activities
       61 electricity and heat producing technologies
       355 end use technologies
       339 processes
       134 energy carriers
       67 materials

Time Period: The US modeling horizon runs in five-year intervals from 1995 – 2050.

Special Features: MARKAL uses a comprehensive framework that addresses interactions and competition between all energy forms and technologies. The system depicted in MARKAL is derived from user-provided data allowing it to be used from global (linking region/country models) and national levels, to states and municipalities.

Treatment of Renewable Energy: MARKAL begins by handling renewable technologies as it does any other. They are characterized by investment and operating costs, and for biomass, by unit energy requirements. Hydro can be modeled as conventional or pumped storage, with the seasonal aspects of any reservoir characterized separately. For renewables such as wind and solar, the specific season/day-night capacity factors describing the operational characteristics of the technologies are provided. Any number of technologies may be described, broken out according to cost, performance, or siting criteria. These values may change over time. For targeted technologies of interest, endogenous technology learning can be employed to examine the drop in investment cost of the technologies as their deployment increases.

Major Users/Applications: MARKAL has been deployed in over 50 countries and 110 institutions. Those government and research institutions from countries participating in ETSAP are the heaviest users of the model, along with a growing number of transition and developing

countries. It is increasingly being used with a regional focus (e.g., Central America, ASEAN, APEC, Nordic countries, globally). MARKAL excels in addressing mid to long-term "what if" questions. MARKAL can accommodate a variety of policy objectives (e.g., program/portfolio goals, security issues, emission targets/taxes, etc.) and market analyses that identify optimal energy technologies to meet these objectives. It is very well suited for the establishment of CDM/JI baseline(s) and subsequent emission reduction assessment for proposed projects, as well as valuing the carbon rights and examining emission trading.

Documentation: *Energy/Environmental Modelling Using the MARKAL Family of Models*, Paper by Ad Seebregts (seebregts@ecn.nl), ECN Policy Studies (www.ecn.nl/unit_bs/main.html) and Gary Goldstein (ggoldstein@irgltd.com), IRG (www.irgltd.com), Primary Software Coordinator ETSAP. Presented at and selected for publication in the Proceedings of the OR2001 Conference, Energy and Environment Session, September 3-5, 2001, Duisburg, Germany.

Energy Planning and the Development of Carbon Mitigation Strategies, Using the MARKAL Family of Models Update of a paper by Gary Goldstein, IRG, Primary Software Coordinator ETSAP, and the ETSAP Partners.

URL: Various papers and links to user institutions can be found at the ETSAP website http://www.ecn.nl/unit_bs/etsap/main.html. New system documentation will be available in 2003.